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Resilience to disasters in coastal cities: a study of socio-environmental vulnerability in Itajaí

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Abstract
The municipality of Itajaí, located on the northern coast of Santa Catarina, has an extensive history of disasters, particularly due to the frequent flooding that affects the region. This situation is exacerbated by climate change, which intensifies rainfall patterns and poses the threat of rising sea levels. In this context, the general objective of the article is to classify socio-environmental vulnerability to floods and mass movements in the municipality of Itajaí (SC), aiming to develop disaster resilience strategies. The methodology employed is a case study, utilizing a quantitative, descriptive, and evaluative approach that explores aspects of vulnerability through the application of a bivariate classification model resulting from the construction of indices. The results reveal that approximately 48,000 inhabitants in Itajaí live in areas of high and/or very high socio-environmental vulnerability. There is also significant socio-spatial segregation, with low-income populations concentrated in small areas at high risk of disasters. In contrast, high-income populations reside in verticalized areas

characterized by concentrated investments in risk mitigation. In summary, Itajaí faces a critical increase in vulnerability to disasters, being exposed to the adverse effects of climate change. Given this scenario, it is urgent to consider interventions in the Disaster Risk Management model to strengthen resilience and promote climate adaptation.
Keywords: Socio-environmental disasters. Climate Change. Disaster Risk Management. Vale do Itajaí.

Resiliência aos desastres em cidades costeiras: um estudo de vulnerabilidade socioambiental em Itajaí

Resumo
O município de Itajaí, situado no litoral Norte de Santa Catarina, possui um extenso histórico de desastres, com destaque para as inundações que frequentemente afetam a região. Essa realidade se agrava com as mudanças climáticas, que intensificam o regime de chuvas e trazem a ameaça da elevação do nível do mar. Nesse sentido, o objetivo geral do artigo é realizar uma classificação de vulnerabilidade socioambiental (VSED) às inundações e aos movimentos de massa no município de Itajaí (SC), com vistas a elaboração de estratégias de resiliência aos desastres. A metodologia é um estudo de caso, quantitativo de cunho descritivo e avaliativo, que explora aspectos do estudo da vulnerabilidade, a partir da aplicação de um modelo de classificação bivariado resultado da construção de índices. Os resultados revelam que em Itajaí existem cerca de 48 mil habitantes vivendo em áreas de alta e/ou muito alta VSED. Existe também uma acentuada segregação socioespacial, na qual a população de baixa renda está concentrada em áreas pequenas com alta probabilidade de ocorrência de desastres. Em contraste, a população de alta renda reside em áreas verticalizadas, caracterizada pela concentração de investimentos de atenuação do risco. Em síntese, Itajaí enfrenta um aumento crítico da vulnerabilidade a desastres, estando exposto aos efeitos adversos das mudanças climáticas. Diante desse cenário, é urgente considerar intervenções no modelo de Gestão de Riscos de Desastres para fortalecer a resiliência e promover a adaptação climática.
Palavras–chave: Desastres socioambientais. Mudanças Climáticas. Gestão de Risco de Desastres. Vale do Itajaí.

Resiliencia a las catástrofes en las ciudades costeras: un estudio de vulnerabilidad socioambiental en Itajaí

Resumen
El municipio de Itajaí, situado en la costa norte de Santa Catarina, tiene un extenso historial de desastres, especialmente debido a las inundaciones que afectan con frecuencia la región. Esta realidad se agrava por el cambio climático, que intensifica los patrones de lluvia y plantea la amenaza del aumento del nivel del mar. En este contexto, el objetivo general del artículo es clasificar la vulnerabilidad socioambiental a inundaciones y movimientos de masa en el municipio de Itajaí (SC), con el fin de desarrollar estrategias de resiliencia ante desastres. La metodología empleada es un estudio de caso, utilizando un enfoque cuantitativo, descriptivo y evaluativo que explora aspectos de la vulnerabilidad a través de la aplicación de un modelo de clasificación bivariada resultante de la construcción de índices. Los resultados revelan que aproximadamente 48,000 habitantes en Itajaí viven en áreas de alta y/o muy alta vulnerabilidad socioambiental. También hay una notable segregación socioespacial, donde las poblaciones de bajos ingresos están concentradas en pequeñas áreas con alta probabilidad de desastres. En contraste, las poblaciones de altos ingresos residen en áreas verticalizadas caracterizadas por inversiones concentradas en mitigación de riesgos. En resumen, Itajaí enfrenta un aumento crítico de la vulnerabilidad a desastres, expuesta a los

efectos adversos del cambio climático. Ante este escenario, es urgente considerar intervenciones en el modelo de Gestión de Riesgos de Desastres para fortalecer la resiliencia y promover la adaptación climática.

Palabras clave: Desastres socioambientales. Cambios Climáticos. Gestión del Riesgo de Desastres. Vale do Itajaí.

1 Introduction

Socio-environmental disasters constitute one of the most frequent and destructive phenomena occurring today (Cui *et al*., 2020; Tierney, 2020). According to the report "The Human Cost of Disasters 2000-2019," prepared by the United Nations Office for Disaster Risk Reduction (UNDRR, 2019), between 1980 and 1999, there were 3,656 disasters, while between 2000 and 2019, 7,348 were recorded, representing a 99% increase in the number of occurrences. The report also points out that, during this period, disasters resulted in the deaths of 1.5 million people and generated costs to the global economy of around $2.97 trillion in the last recorded series. According to the Centre for Research on the Epidemiology of Disasters (CRED, 2023), in 2022 alone, 387 disasters were recorded worldwide, resulting in 30,704 deaths and $223.8 billion in economic losses.

In coastal areas, projections regarding disasters are highly critical. According to the report "State of the Global Climate in 2023" (Climate Central, 2023, p.3), [...] "the rise in sea levels as a result of climate change is expected to put locations that are home to around 100 million people in the world at risk by the end of this century". According to the data analyzed, the average global sea level rise rate over the past decade (2014-2023) is more than double the rate of sea level rise in the first decade of satellite records (1993-2002) (IPCC, 2023). In Brazil, the most significant disasters occurred in coastal areas or within 100 km of the coast, predominantly related to mass movements and floods. Notable events include the tragedy in Petrópolis in 2022, which resulted in 241 deaths (Blaudt; Alvarenga; Garin, 2023); the disaster in the Serrana Region of Rio de Janeiro in 2011, with 918 fatalities; the heavy rains in the North Coast of São Paulo in February 2023, which claimed 59 lives and left 4,000 displaced (CRED, 2023); and in 2022, the coastal State of Pernambuco was hit by heavy rains that resulted in 133 deaths and 2,099 people displaced.

The problem becomes even more severe, as 54.8% of the Brazilian population and 70% of the country's Gross Domestic Product (GDP) are concentrated in the Atlantic Forest Biome, especially in areas up to 150 km from the coast (Ministry of the Environment and Climate Change, 2023). This biome features various ecosystems highly susceptible to geological and hydrometeorological phenomena, characterized primarily by steep terrain, an abundance of watercourses, drainage zones of significant rivers, and high levels of precipitation (Pereira, 2009). Additionally, there is an accelerated process of urbanization that is not adapted to these natural characteristics. In this catastrophic scenario, 2.1 million people could be highly affected by annual flooding driven by rising sea levels in Brazil's coastal regions by 2100 (Climate Central, 2023).

In this context of increasing disaster impacts in Brazil, the phenomenon of increasing social vulnerability adds to the problem. The precariousness of working conditions has substantially increased the vulnerability of middle-class families and the poorest, expanding the population living in peripheries and favelas, and consequently, areas at risk (Krein; Colombi, 2019). Another aggravating factor has been the reduction in investments in disaster prevention. According to the Open Accounts Agency (2023), the budget allocated for Disaster Risk Management (DRM) experienced gradual cuts, decreasing from $1 billion in 2014 to $250 million in 2022.

The Itajaí Valley region (SC), in southern Brazil, is an Atlantic watershed where more than 100 floods and numerous mass movements have been reported since the beginning of colonization in 1850 (Civil Defense of Blumenau, 2024). The National Center for Monitoring and Early Warning of Natural Disasters (CEMADEN, 2024) states that the region is among the five most affected by disasters in Brazil this century. Among the most catastrophic events are the "floods of 1983," which impacted 135 municipalities, leaving about 198,000 people displaced and 49 dead. In November 2008, the most severe event in the region's history occurred. More than 1.5 million inhabitants were affected, resulting in 135 deaths and about 80,000 displaced (World Bank, 2012; Queiroz, 2009, p. 9; Ávila; Mattedi, 2017). In 2021, mass movements and flash floods caused 21 deaths and 172 people displaced (Michel *et al*., 2020). In October 2023, the region faced several floods, resulting in two deaths and around 25,000 people displaced (Civil Defense of Santa Catarina, 2023).

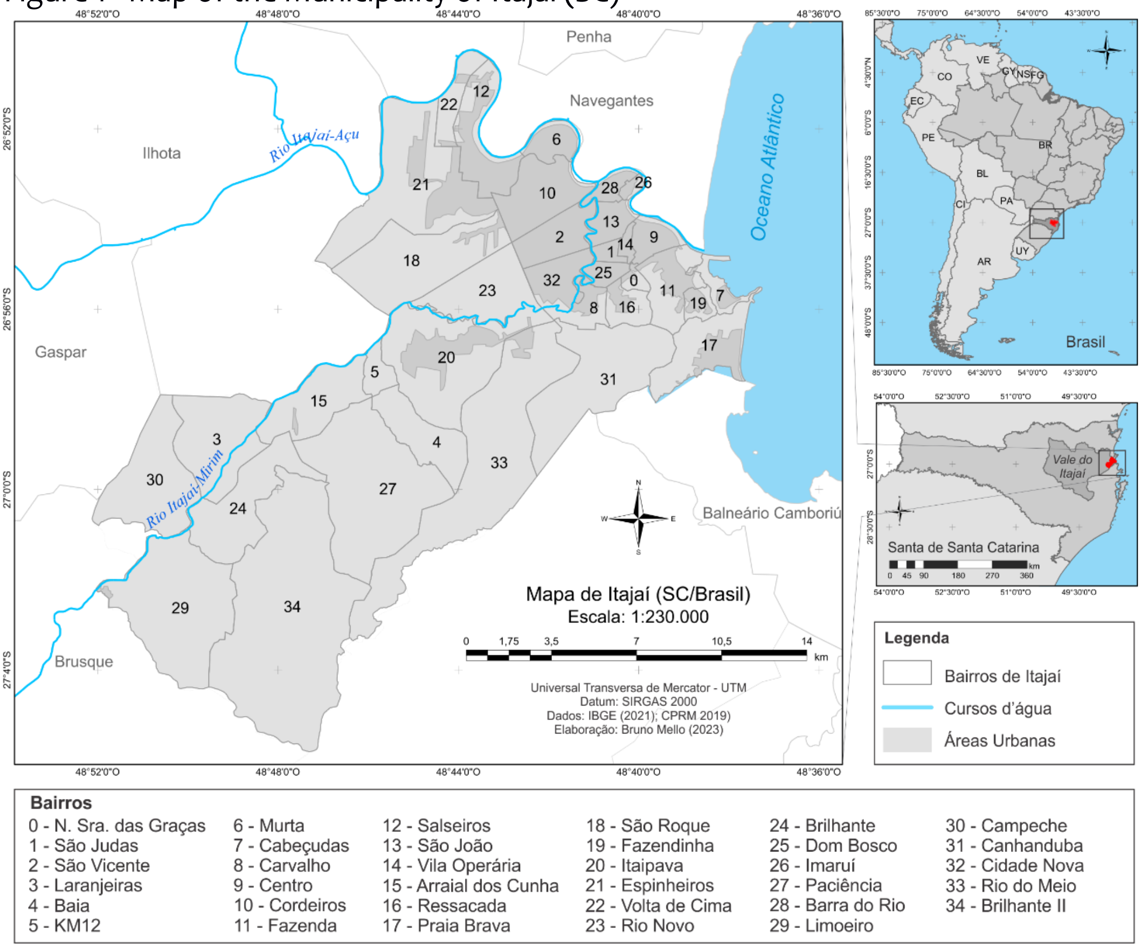
The municipality of Itajaí, located in the estuarine zone of the Itajaí-Açu River, is one of the most affected by natural disasters in the Itajaí Valley region, and there is a concerning trend of increasing records and intensity of disaster impacts in recent years. This may be related to three global phenomena affecting various coastal areas worldwide: i) Climate change is intensifying the impacts of extreme weather events and altering ocean dynamics (IPCC, 2023; UNDRR, 2019); ii) Real estate speculation and the expansion of tourism often displace the most vulnerable to susceptible areas, increasing exposure to disaster risk; and iii) Port activities, the construction of tourism-real estate developments, and accelerated urbanization have caused the degradation of vital ecosystems, such as coral reefs, mangroves, sandbanks, and estuaries, reducing the protective and absorptive capacity in these areas. The hypothesis is that these factors may be increasing the population's vulnerability to disasters in Itajaí by diminishing the municipality's protective capacity, pushing both community and ecological resilience to their limits.

In this context, the general objective of the article is to conduct a classification of socio-environmental vulnerability to floods and mass movements in the municipality of Itajaí (SC), with a view to developing disaster resilience strategies. Thus, the methodology explores aspects of disaster risk assessment through the application of a bivariate classification model. This research can be used to enhance the adaptive capacity of cities and regions, thereby accelerating their urban planning efforts, culminating in proposals for strengthening disaster resilience in the region. Therefore, the aim is to contribute to disaster risk reduction actions that emphasize local proactivity and are not limited to responses to climate emergencies. In addition to this introduction, the article is divided into four parts: i) the occurrence of disasters in Itajaí; ii) applied methodology; iii) results and discussion; and iv) conclusions.

2 The Production of Socio-environmental Disasters in Itajaí (SC)

The municipality of Itajaí (Figure 1) is part of the Itajaí River watershed and integrates the Atlantic slope drainage system. The municipality was colonized by Portuguese, Azorean, and Madeiran immigrants in the 18th century, and it was officially established in 1884. It covers an area of 289 km², with elevations ranging from 0 to 100 meters above sea level. Its population is estimated at 264,054 inhabitants (IBGE, 2022). The economy is based on logistics activities (port area) and tourism (Polette, 2012).

Figure 1 - Map of the Municipality of Itajaí (SC)

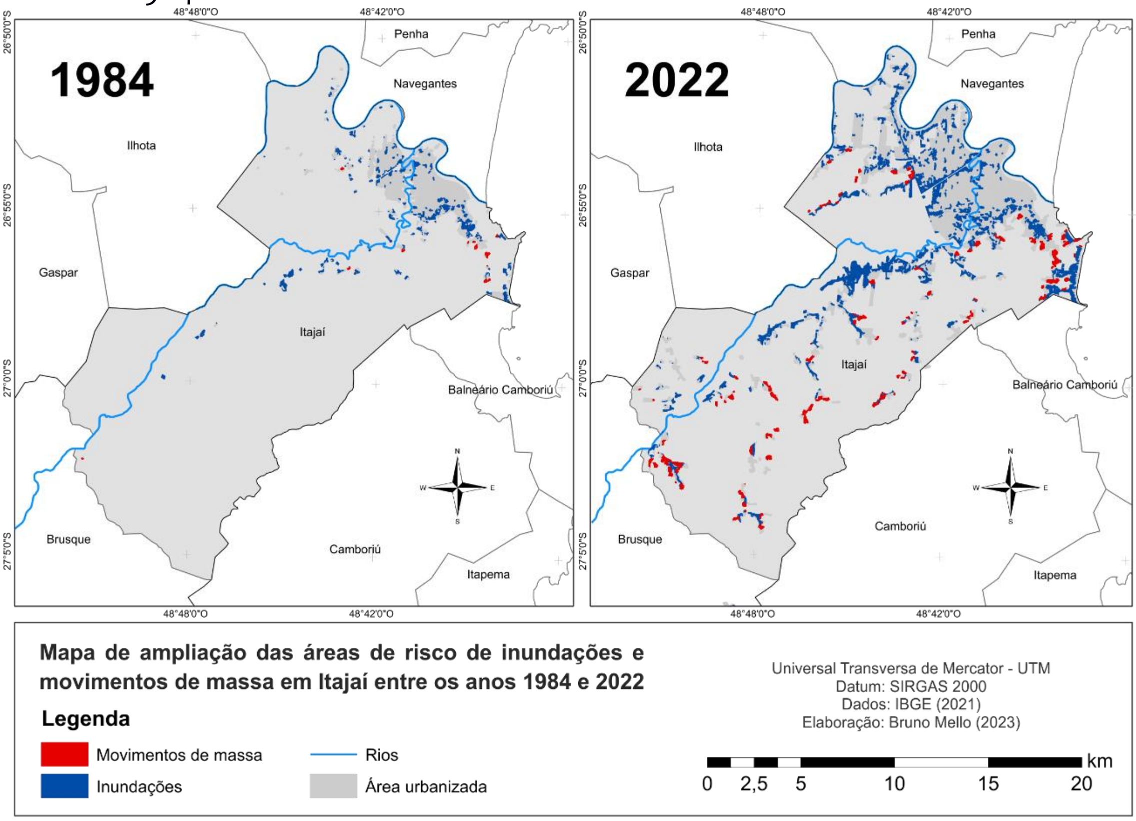


Source: Prepared by Mello (2024) based on IBGE data (2021).

Historically, the municipality of Itajaí has been marked by disasters characterized by flooding, and in recent years, the recording of mass movements has also intensified. The constant occurrence of socio-environmental disasters in Itajaí is a result of an urbanization process based on a mindset of constant conflict with the natural environment, with attempts to adapt it to human needs (Ávila; Mattedi, 2017). In 1983, Itajaí was severely affected by the waters of the Itajaí-Açu River and the Itajaí-Mirim River, which destroyed part of the port's dock and left thousands homeless. During the disaster of 2008, 85% of Itajaí's urban area was flooded, resulting in 5 deaths and over 40,000 people displaced (World Bank, 2012). The Port of Itajaí was impacted, with part of the dock destroyed and the loss of containers, leading to a loss of $169 million. In 2023, flooding occurred that left many homeless and caused significant material damage.

Figure 2 illustrates the growth of the population in risk areas between 1984 and 2022. There has been an exponential increase in risk areas, driven by unplanned urban growth. In 1984, risks were primarily concentrated in the center, especially in flood-prone zones. In contrast, by 2022, there was an expansion of the population into peripheral areas, increasing the risk of mass movements and flash floods.

Figure 2 - Map of the expansion of flood and mass movement risk areas in Itajaí between 1984 and 2022



Source: Prepared by Mello (2024) based on vector data from Mapbiomas (2022); Geological Survey of Brazil (CPRM), Parisi and Bellettini (2019), and IBGE (2021).

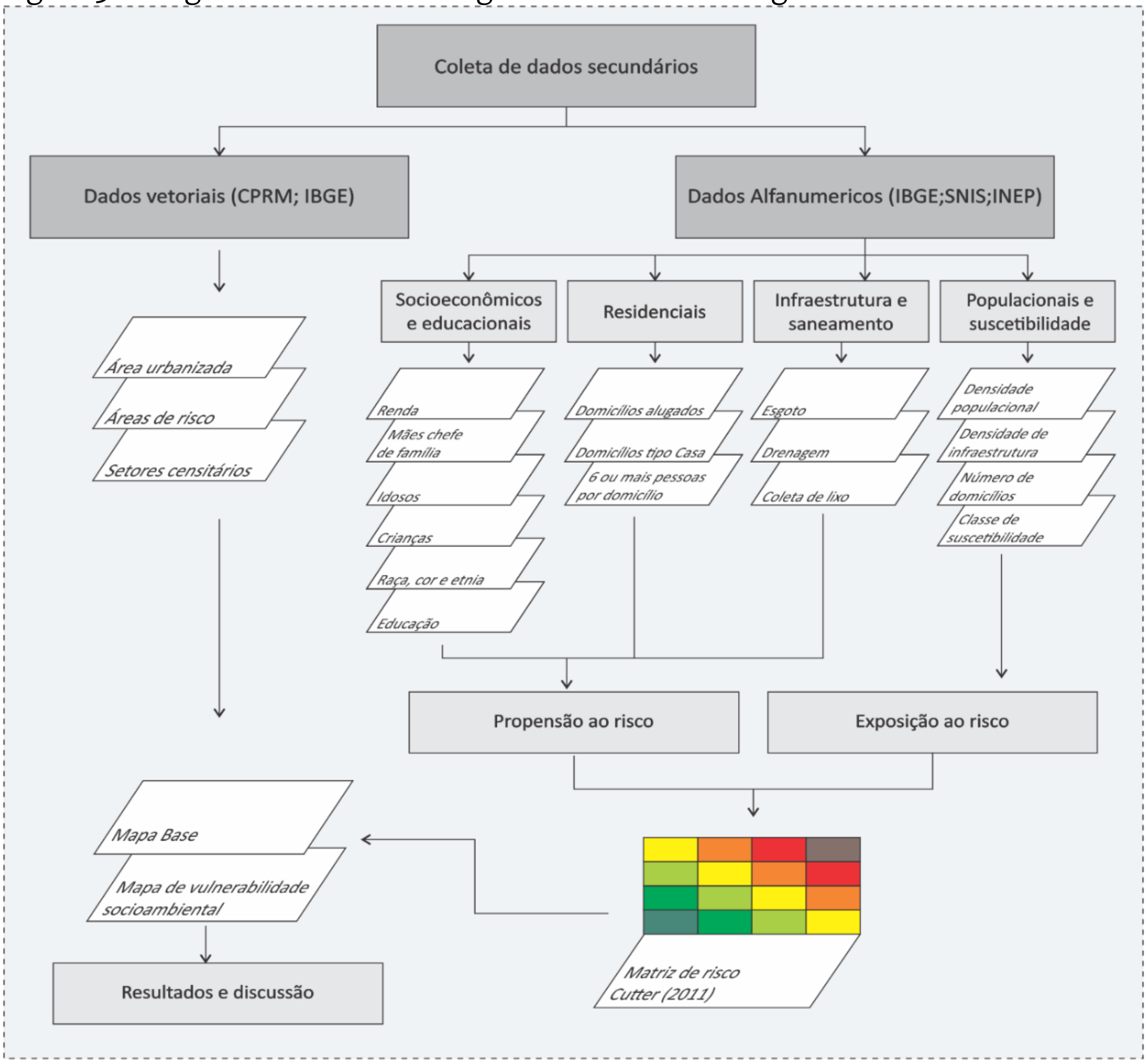
In the case of Itajaí, risk areas have developed due to four main factors: 1) the development model that offers a high availability of jobs in the industrial, port, and general service sectors; 2) high population growth driven by migration (above the national average), with a growth rate of 5.5% per year (IBGE, 2010; 2022); 3) the expansion of real estate speculation, which has led the region to have some of the highest land prices in the country (Fipezap, 2023); and 4) the occupation of environmentally sensitive areas, such as mangroves, riparian forests, and slopes, which is closely linked to real estate speculation, social vulnerability, and the absence of an effective housing policy (CEMADEN, 2024).

While there is a trend of increasing frequency of extreme hydrometeorological events, Jansen *et al*. (2021) and Joner, Ávila, and Mattedi (2021) identified a certain fragmentation of Disaster Risk Management (DRM) among the municipalities of the Itajaí Valley, as well as the centralization of actions by the State Civil Defense. The lack of social participation in DRM processes and urban planning has also worsened the disaster problem. Furthermore, regarding sea level rise in the municipality of Itajaí, the situation becomes even more critical, as eustasy will have direct impacts on the economy, affecting the port area as well as various riverside localities (Gomes, 2018).

3 Methodology

This is a research study with a quantitative, descriptive, and evaluative approach that uses alphanumeric data from socioeconomic variables and environmental susceptibility in Itajaí (SC). The data collected were organized, transformed into attributes, normalized, and grouped into two main dimensions, revealing: an Exposure to Risk Indicator (ER) and a Risk Propensity Indicator (PR). Subsequently, the constructed indicators (ER and PR) were intersected in Cutter's Risk Matrix (2011). This process allowed not only the construction of a Vulnerability Indicator (VSED) but also the creation of a thematic VSED map. Figure 3 presents a flowchart of the applied methodology:

Figure 3 – Stages of the Methodological Procedure of Stage 1



Source: Prepared by the authors (2024).

Exposure to Risk (ER) refers to the population and urban infrastructures located in areas predisposed to the impact of a particular threat/hazard. ER aims to quantify the number of people (potential loss of life) and the amount of infrastructure at risk (potential economic losses). The selection of these variables was based on the literature by Burton, Kates, and White (1993), Anderson (2000), and Ruiz (2012).

Table 1 - Variables of Exposure to Risk (ER)

Variables	Description	Weight (p)
Population Density (inhabitants/ha) x risk sector (IBGE, 2022)	The higher the concentration of people in risk areas, the greater the potential for victims.	0,400
Urban Infrastructure Density (buildings/ha) x risk sector (IBGE, 2022)	Trends to increase the potential for material losses, hindering recovery and raising disaster costs. It considers the amount of debris that can affect people, causing injuries and fatalities.	0,150
Number of Residences in the Risk Sector (IBGE, 2022)	The more households in a risk sector, the greater the urban infrastructure exposed to the direct and indirect impacts of disasters. The more residences affected, the higher the number of displaced and homeless individuals.	0,150
Classification of Susceptibility to Mass Movements (CPRM, Parisi; Bellettini, 2019)	Probability of a mass movement occurring in a specific location. Also known as landslides, slope failures, and barrier collapses, they refer to the downward movement of soil and rock under the influence of gravity, often intensified by water action.	0,150
Classification of Susceptibility to Flash Floods (CPRM, Parisi; Bellettini, 2019)	Probability of a flash flood occurring in a specific location. A flash flood is a rapid flow of water resulting from intense or sudden rainfall. It can cause flooding, carry debris, and inflict significant damage to infrastructure and properties, posing a risk to people's safety.	0,150
Classification of Susceptibility to Flooding (CPRM, Parisi; Bellettini, 2019)	Probability of flooding occurring in a specific location. Floods are generally understood as the result of excessive water concentration that cannot be absorbed by already saturated soil and other forms of runoff, for example, in impermeable urban areas, where water flows rapidly to low-lying areas and rivers, exceeding drainage capacity and causing banks to overflow.	0,150

Source: Prepared by the authors, based on the Demographic Census, IBGE (2022), CPRM, Parisi, and Bellettini (2019).

Risk Propensity (PR) relates to the socioeconomic impacts of a disaster (Social Vulnerability). To calculate PR, characteristics of the population that may diminish their capacity for response, absorption, and recovery after a disaster are considered

(Cutter, 2011). The variables were chosen through the Social Vulnerability Index (SOVI®) (Hummel; Cutter; Emrich, 2016).

Table 2 – Risk Propensity Factors

Variáveis	Descrição	Peso
Average Family Income (IBGE, 2022)	Average family income is one of the fundamental factors influencing the population's propensity to disaster risk (UNISDR, 2015).	0,400
% Single Mothers (IBGE, 2010)	A high percentage of single mothers in an area contributes to social vulnerability, especially regarding the capacity for response and recovery in the face of disasters. This is because their income is often lower than that of males and couples, limiting their options and resources in crisis situations (IPEA, 2017).	0,050
% Elderly Population (over 60 years) (IBGE, 2022)	An elderly population in a sector constitutes vulnerability due to factors such as increased frailty, cognitive decline, and difficulty in mobility during emergencies.	0,075
% Child Population (up to 12 years) (IBGE, 2022)	According to Fonseca et al. (2013), a high number of children constitutes vulnerability due to their lower capacity to respond to danger (financially, cognitively, understanding the problem, decision-making, among others).	0,075
% Black, Mixed Race, or Indigenous Population (IBGE, 2010)	Black, mixed race, or indigenous populations are groups with a higher number of individuals in social vulnerability and a greater propensity to occupy risk areas (Rocha, 2020).	0,050
IDEB - Basic Education Development Index (INEP, 2019)	For Cury (2007), education is a fundamental right for citizens and should be guaranteed without distinction of social class or ethnicity, as the purpose of school is to promote learning and inclusion, mitigating social inequalities and vulnerabilities.	0,050
% Permanent Private Households with 6 or More Residents (IBGE, 2010)	Indicates the population density in residences in risk areas, which amplifies the vulnerability situation. More people may be impacted by disasters (UNISDR, 2015).	0,050
% Rented Households (IBGE, 2010)	Populations in rented households tend to lack identity with the location—reducing knowledge, response, and engagement for management—and have a lower capacity to invest in property to absorb impacts (Cutter, 2011).	0,050
% Permanent Households with Single-Story Houses (IBGE, 2010)	The variable "single-story house," especially when precarious, tends to have lower structural capacities to absorb impacts, making them more vulnerable to damage from floods, landslides, and flash floods (Cutter, 2011).	0,050
% Households with Sanitation (SNIS, 2023)	Influences the exacerbation of the impacts of climate events, implying not only environmental degradation but also difficulties in recovery of affected areas.	0,025
% Roads without Rainwater Drainage (SNIS, 2023)	It has a direct impact on enhancing floods, landslides, and flash floods (Tasca; Pompeo; Finotti, 2017).	0,100
% Households without Adequate Waste Collection (SNIS, 2023)	Accumulated waste/solid waste in roads directly impacts rainwater drainage, as there is potential for clogging of drains, ditches, drainage channels, etc.	0,050

Source: Prepared by the authors (2024), based on the Demographic Census, IBGE (2022; 2010), INEP (2019), and SNIS (2023).

The alphanumeric data for the Exposure to Risk (ER) and Risk Propensity (PR) variables from the census sectors were collected and organized in Microsoft Excel. The next step was to normalize these variables, a process that transforms measures from different scales into a common scale, facilitating comparison. The applied technique was min-max, where the values are calculated based on the fraction between the occurrence of the variable in the sector and the total number of households or people. Normalization adopted 0 as the ideal and 1 as the worst situation.

To carry out the normalization process for the variables, Equation (1) was used in one case and Equation (2) in another: for variables that have attributes directly related to vulnerability (the higher the variable's value, the lower the vulnerability), Equation (1) was used. For variables indirectly related to vulnerability (the lower the variable's value, the higher the vulnerability), Equation (2) was applied.

$$\mathrm{Ips} = \frac{\mathrm{Is} - \mathrm{Imin}}{\mathrm{Imax} - \mathrm{Imix}} \cdot \mathrm{p} \quad (1)$$

$$\mathrm{Ips} = \frac{\mathrm{Is} - \mathrm{Imax}}{\mathrm{Imin} - \mathrm{Imax}} \cdot \mathrm{p} \quad (2)$$

Where,
Ip: normalized value of the variable in the census sector;
Is: original value of the variable in the census sector;
Imax and Imin: respectively, the maximum and minimum values of the variable within the universe of census sectors.
P: refers to the weight applied to each variable.

With the acquisition of the normalized attributes (Ips) for each variable, it is possible to calculate the Exposure Indicator and the Risk Propensity Indicator using Equation (3).

$$\mathrm{IVs} = \frac{\sum_{i=1}^{n} \mathrm{Ips}}{n} \quad (3)$$

Where,
IVs: value of the propensity and/or exposure indicators in the census sector of the municipality;
n: corresponds to the total number of selected variables by dimension;
i: considers the variation of results between 0 and 1;
Ips: corresponds to the normalized value of the variable in the census sector.

The next step of the methodology involves the intersection of the exposure and risk propensity attributes. This allowed for the establishment of the Vulnerability Indicator (VSED) classification (Cutter, 2011). This is the convergence of extreme "explosive" situations that involve the occurrence, at the same time and space, of numerous stressors of both natural and anthropogenic origin (Ludwig; Mattedi, 2016). Thus, when these vulnerabilities intersect and interact, they produce harmful outcomes for a given population and the surrounding environment; that is, the greater the number of people in social vulnerability occupying areas of high environmental susceptibility, the more concerning the community condition becomes.

In this way, the classification of VSED is determined in the impact matrix (Table 4): EB – Very Low – dark green; B – Low – green; MB – Medium Low – light green; M – Medium – yellow; MA – Medium High – orange; A – High – red; EA – Very High – ochre. The result of this interaction captures the dynamics that configure a specific spatiality, aiming to circumscribe its scale. The intersection of the ER and PR indicators employed computational programming, using a statistical learning algorithm called Frequency Ratio, developed in Python.

Table 3 – Impact Matrix

		Exposição ao risco (ER)									
Propensão ao risco (Pr)		0 - 0,099	0,100-0,199	0,200-0,299	0,300-0,399	0,400-0,499	0,500-0,599	0,600-0,699	0,700-0,799	0,800-0,899	0,900-1
	0,900 – 1	M	M	MA	MA	A	A	EA	EA	EA	EA
	0,800-0,899	M	M	M	MA	MA	A	A	EA	EA	EA
	0,700-0,799	MB	M	M	M	MA	MA	A	A	EA	EA
	0,600-0,699	MB	MB	M	M	M	MA	MA	A	A	EA
	0,500-0,599	B	MB	MB	M	M	M	MA	MA	A	A
	0,400-0,499	B	B	MB	MB	M	M	M	MA	MA	A
	0,300-0,399	B	B	B	MB	MB	M	M	M	MA	MA
	0,200-0,299	EB	B	B	B	MB	MB	M	M	M	MA
	0,100-0,199	EB	EB	B	B	B	MB	MB	M	M	M
	0 – 0,099	EB	EB	EB	B	B	B	MB	MB	M	M

Source: Prepared by the authors (2024) based on Cutter (2011)

For the construction of the base map, the vectors from the census sectors of IBGE (2021) were used. This cartography is essential, as the alphanumeric census data can only be applied in mappings through this vector. The vector data (areas of high susceptibility to mass movements, built urban areas, and municipal boundaries) were provided by CPRM, Parisi, and Bellettini (2019). Using Geographic Information Systems (GIS) Esri ArcGIS 10.8©, the maps of areas susceptible to floods, mass movements, and flash floods (CPRM, 2019), urban sprawl, and census sectors from IBGE (2021) were overlaid. Thus, the VSED classification, obtained from the intersected alphanumeric data, was related to the base map, resulting in the development of the VSED map of Itajaí (Figure 4).

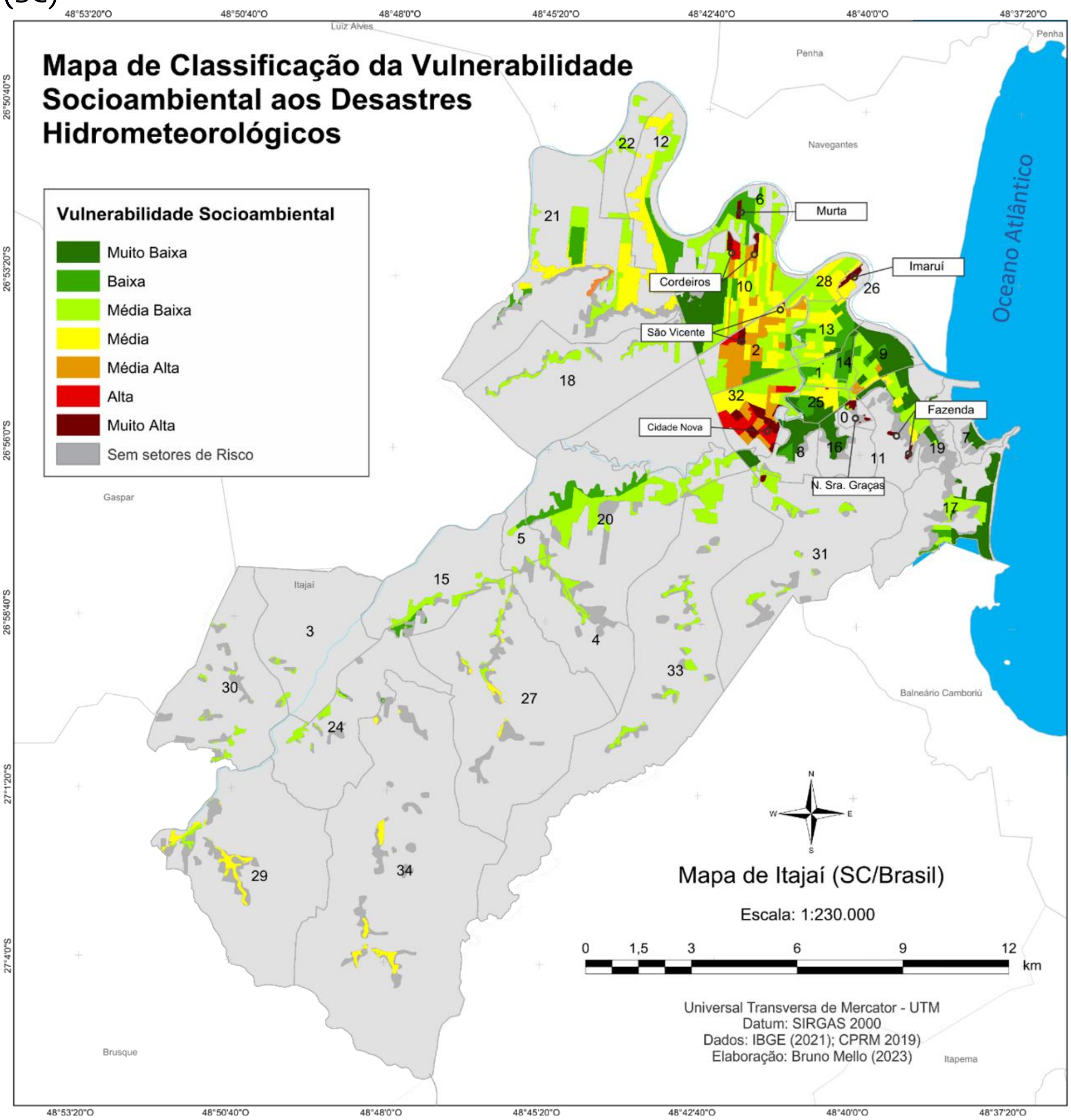
4 Results and Discussion

In Itajaí, the ER index is 0.537, while the PR index is 0.501, classifying the municipality as Medium VSED. Of the 310 census sectors delineated for the municipality of Itajaí (SC):

29 are classified as Very Low VSED, a total of 1,238 hectares, which represents 4% of the municipality's area. These sectors have a population of 10,868 inhabitants

and 3,864 homes, most of which are high-rise buildings. The average family income of this population is 7.8 minimum wages per month. The neighborhoods with the highest occurrence of Very Low VSED are located in Centro, Praia Brava, Fazenda, São João, Cabeçudas and Ressacada. Figure 4 shows the VSED classification map for Itajaí:

Figure 4 - Map of Socioenvironmental Vulnerability Classification to Disasters in Itajaí (SC)



Source: Prepared by Mello (2024).

22 sectors were classified as Low VSED, covering a total area of 1,917 hectares (5% of the municipality's area). They have a population of 11,864 inhabitants in 3,874 residences. The average family income for this population is 5 minimum wages per month. The neighborhoods with the highest occurrence of Low VSED are Centro, São João, Praia Brava, Fazenda, Dom Bosco, Cabeçudas, and Ressacada.

91 sectors were classified as Medium Low VSED, totaling an area of 18,427 hectares, or about 64% of the municipality's area. The population is 75,966

inhabitants in 24,460 residences, with an average family income of 3.1 minimum wages per month.

41 sectors classified as Medium VSED cover an area of 10,116 hectares, approximately 35% of the municipality's area. This area has a population of 27,722 inhabitants in 8,691 residences, with an average family income of 2.5 minimum wages per month.

54 sectors classified as Medium High VSED are located in an area of 453 hectares (0.20% of the municipality's area). The population is 31,620 inhabitants in 9,929 residences, with an average family income of 2.2 minimum wages per month.

38 sectors classified as High VSED occupy a total area of 324 hectares, representing 0.18% of the municipality's area. These sectors have a population of 25,091 inhabitants in 7,818 residences, with an average family income of 2 minimum wages per month. The census sectors with the highest occurrence of High VSED are mainly located in the neighborhoods of São Vicente, Barra do Rio, Cordeiros, and Cidade Nova.

33 sectors were classified as Very High VSED, covering a total area of 194 hectares, which represents 0.12% of the municipality's area. These sectors have a population of 23,287 inhabitants in 6,868 residences, with the majority consisting of precarious wooden houses, such as stilt houses, and exposed masonry. The average family income for this population is 1.8 minimum wages per month. The census sectors with the highest occurrence of Very High VSED are primarily located in the neighborhoods of São Vicente, Imaruí, Canhanduba, Nossa Senhora das Graças, Cordeiros, Cidade Nova, Fazenda, and Murta.

In this context, the most critical risk areas in Itajaí were identified: i) Cidade Nova; ii) Imaruí (Barra do Rio); iii) Nossa Senhora das Graças; iv) communities in the Fazenda neighborhood; v) São Vicente; vi) Murta; and vii) Cordeiros. In the São Vicente neighborhood (Figure 5A), the areas of greatest vulnerability are located at the ends of the roads that border the channelized and non-channelized arms of the Itajaí-Mirim River. Both areas exhibit a similar risk landscape, with dozens of single-story wooden houses built along the banks of the non-channelized arm of the Itajaí-Mirim River.

The Cidade Nova neighborhood (Figure 5B) has hundreds of wooden houses situated along the banks of the Itajaí-Mirim River, in mangrove and riparian areas. These urban occupation conditions pose serious risks to the residents in these areas, as the precarious housing is highly vulnerable to disasters. The Imaruí community (Figure 5C) is located along the banks of the Itajaí-Açu River and is frequently affected by floods and high tide effects. Approximately 1,200 residences are in a state of high precariousness, lacking essential infrastructure such as general sewage collection and treatment systems, as well as stormwater drainage systems. In the Cordeiros neighborhood (Figure 5D), several residences are also exposed to frequent flooding from the Itajaí-Açu River. On the other hand, the Nossa Senhora das Graças communities and some impoverished areas in the Fazenda neighborhood are extremely vulnerable to flash floods and landslides. In these areas, one can observe cuts and fills on slopes and the devastation of environmental preservation areas.

Figure 5 – Areas of High and Very High VSED in Itajaí

Legenda: A - Bairro São Vicente; B – Bairro Cidade Nova; C – Bairro Imaruí; D – Bairro Cordeiros

Source: Prepared by the authors (2024).

Based on the results of this analysis, it is possible to conclude that the propensity to risk has played a decisive role in the increase of VSED (Vulnerability to Social and Environmental Disasters). It is evident that there is a significant socio-spatial inequality, as 17% of the population lives in areas classified as high and very high VSED, which represent only 0.30% of the municipality's total territory. In contrast, the areas classified as Very Low to Medium Low VSED encompasses about 36% of the population and covers more than 70% of the total area. This indicates that low-income populations are concentrated in districts of poverty in high-risk areas, while those with higher family incomes reside in less dense, more expansive, and lower-risk regions.

In areas of high and very high VSED, investments in disaster protection infrastructure have been insufficient. Otherwise, in low VSED locations, there have been significant public efforts to enhance protective capacity, including the construction of stormwater drainage systems, retaining walls, and containment dikes. These measures have led to a clear disparity between central and peripheral areas, concentrating risk mitigation investments in economically favorable regions and consequently increasing vulnerability in peripherical areas. Thus, in Itajaí, it can be asserted that the more protective measures an area has, the greater the interest from real estate groups in that region, resulting in gentrification processes. Low-income populations find themselves unsupported by the lack of an effective housing policy, forcing them into high-risk areas.

According to data from the Municipal Civil Defense of Itajaí (2023), most occurrences registered during the floods of October and November 2023 were in areas classified as Medium High to Very High VSED. A total of 500 people were displaced, and 260 flooding occurrences were recorded across 149 streets in the municipality. Among these occurrences, 41 roads belonged to the Cordeiros neighborhood, 39 to the Murta neighborhood, 29 to the Cidade Nova neighborhood, 22 to the São Vicente neighborhood, and 28 to the Barra do Rio neighborhood, including Imaruí.

It is evident that Itajaí is experiencing an intense process of precarious inclusion, as described by geographer Rogério Hasbaert (2004). This phenomenon is linked to the development model. The absence of effective housing policies contributes to vulnerable individuals occupying disaster-prone spaces without adequate prevention measures. The scenario reveals a genuine "industry of vulnerability" or even "planning for disasters," where the lack of strategies for appropriate land-use planning and the provision of decent housing perpetuates the cycle of precarious housing. Moreover, a perverse action by the real estate market is observed, as it seeks to prevent the emergence of new precarious areas near valued regions, thereby preserving land value. The establishment of risk areas in the region results from a complex interaction of socioeconomic, political, and environmental factors, leading to the deterioration of local resilience.

Finally, six main strategies are highlighted to strengthen the resilience of coastal cities in the face of climate emergencies:

1. **Increase resistance and absorption capacity**: Implement safety structures adapted to the local physical environment, universalize basic sanitation, monitor and prevent new occupations in risk areas, and renaturalize watercourses, mangroves, and coastal areas. The recovery of forests and riparian vegetation should also be prioritized, along with the implementation of small-scale sponge city concepts. This may also involve the sustainable and socially just relocation of residents in extremely necessary cases.
2. **Participatory house planning**: Focus on reducing socio-spatial inequalities, preventing the increased exposure of people and infrastructure in risk areas, and fundamentally curbing the progression of real estate speculation in the municipality, ensuring the right to the city.
3. **Encourage and strengthen community support networks**: Map neighbor networks, social organizations, NGOs, and associations of merchants and entrepreneurs. This collaborative approach aims to contribute to local Disaster Risk Management (DRM), promoting solidarity and information exchange among community members while facilitating mobilization and organization during emergencies.
4. **Promote social participation in decision-making**: Include all segments of civil society in DRM processes, fostering greater autonomy and interrelationship among Civil Defenses. Furthermore, the creation of a Civil Defense at the watershed level is suggested.

5. **Improve risk communication**: Existing systems are efficient, but effective strategies need to be developed to inform the population about risks, aiming to overcome the impacts of alarms and false news. This could include awareness campaigns and collaboration with local media to disseminate accurate and reliable information.
6. **Develop programs with communities in a transdisciplinary manner**: Understand the environment in which they live and prepare for disasters. Stimulate community learning about environmental risk signals and government alert systems through awareness programs, training, and simulations that teach how to identify these signals and use available alert systems. Additionally, education on urban planning and safe, sustainable construction methods is essential, implementing courses and workshops addressing responsible urbanism practices and construction techniques that ensure the safety and sustainability of housing.

Ultimately, the low resilience of the population perpetuates a cycle of vulnerability, where the difficulty of full recovery after a disaster increases the likelihood of future crises. This situation can lead to the continuous deterioration of socioeconomic and environmental conditions. Therefore, overcoming low resilience goes beyond a mere technical or subjective issue; it involves a profound transformation in how we approach development. It requires a significant commitment to structural changes aimed at building more robust and adaptable societies to emerging socio-environmental challenges. Advancing disaster resilience emerges as a fundamental factor for strengthening regions in the face of climate change, but progress is challenging due to the need for a fundamental shift in the development paradigm.

5 Conclusions

Itajaí has witnessed remarkable population growth, driven by the expansion of port activities, transportation and logistics services, construction, the textile industry, and more. This growth has been accompanied by the attraction of migrants seeking opportunities, often without adequate knowledge of the risks they will be exposed to. This scenario of rapid population growth has resulted in communities that lack proper preparation and have a limited capacity to recover after disasters occurrence. In this sense, it seems pertinent to reconsider the current Disaster Risk Management (DRM) model, focusing on a new model that not only aims to ensure the rapid reconstruction of degraded areas after a crisis but also to strengthen the continuous awareness of the population regarding risks and increase their autonomy in future disasters.

The combined study of exposure and propensity to risk is important for understanding disasters in coastal areas, as these two dimensions are fundamental for analyzing a community's ability to face adverse events. This study can theoretically contribute to the development of research that focuses on proactivity regarding disasters and does not limit itself to responses in situations of action and reaction. However, there are few methods that aim to quantify the relationship between socioeconomic and environmental factors in exacerbating the risks of socio-environmental disasters. The concept of vulnerability proposed by Cutter (2011) is considered an appropriate approach for the Brazilian situation.

The practical contribution of this study arises from the fact that mapping socio-environmental vulnerability (SEV) can be an important tool for DRM, as it allows for the identification of the most vulnerable areas to socio-environmental disasters and the population groups with the greatest potential impact. Based on this information, authorities can better implement preventive and mitigation plans and actions. Thus, financial resources can be better allocated to the places and populations that need it most. Mapping can contribute to raising awareness among the population and authorities about the importance of management and the adoption of preventive plans and actions against disasters.

The method relies on widely available geospatial tools and technologies. The multidisciplinary approach allows for the adaptation of the method to different types of risks and socioeconomic and environmental contexts. Measurement and mapping of social and physical vulnerability can be adapted to different geographical scales, from local communities to entire countries and regions. However, it is important to remember that the replicability of the method may depend on the availability of accurate and up-to-date geospatial and socioeconomic data, as well as the ability to gather and integrate information from different disciplines. Future studies will consider not only one municipality but also areas in the Vale do Itajaí region.

The main limitation of this study is the database from IBGE. The 2022 Census data is in a preliminary phase, which may lead to distortions, particularly in socioeconomic data, given the likely increase in social vulnerability. The 2010 data is outdated and no longer accurately represents the local reality. This means that the vulnerability reflected in the city's landscape may appear to be greater than indicated by the results of this article. Additionally, an observational field study was conducted to minimize serious distortions of the socio-spatial reality.

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